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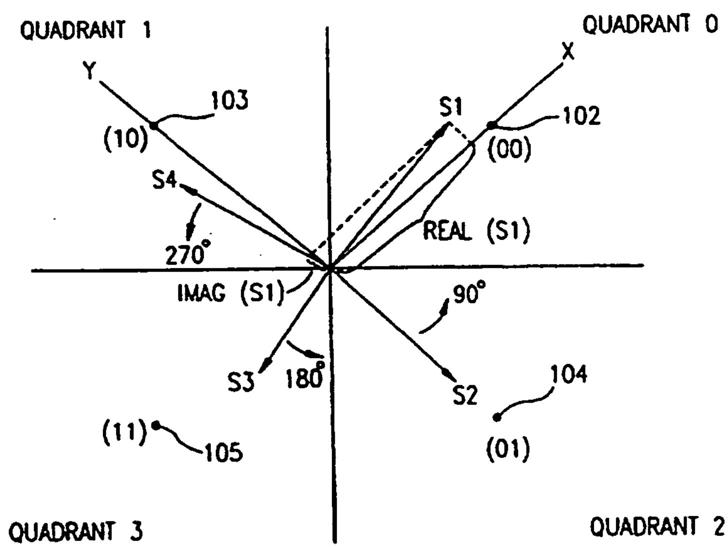

(57) Abstract

Apparatus and method for calculating the channel state associated with received signals are disclosed. The channel state is determined from the received signal by analyzing the received signals. Also, apparatus and method for performing erasures of the received signals and for selecting between diversity communication signals based on the channel state are disclosed.

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APPARATUS AND METHOD FOR DETERMINING AND USING CHANNEL STATE INFORMATION

Background Of The Invention

The present invention relates to wireless communications. More particularly, it relates to apparatus and methods for determining the state of a frequency channel in a wireless communication channel and for using the channel state information.

As is well known, a frequency channel in a wireless communication channel is subject to many sources of degradation. Thus, communication signals will not always be communicated properly on a frequency channel. When operating a wireless communication system, it is desirable to be able to determine the "state" of a frequency channel in order to determine the likelihood of acceptable communication on the frequency channel. While channel estimators are known in the art, none adequately performs the tasks of determining the state of a frequency channel. Another shortcoming of existing communication systems is found in the usage of channel state information.

Thus, apparatus and method for determining the state of a frequency channel are needed. Further, apparatus and method for using the channel state information to control the operation of the communication system to achieve improved communication are also needed.

Summary Of The Invention

The present invention provides apparatus and method for determining and using channel state information. In accordance with one aspect of a preferred embodiment of the present invention, channel state information is derived from a set of communication symbols received during an individual time slot, although any set of communication signals or even a single communication signal can be used. For each of the received communication symbols, QPSK modulated symbols are hard detected to determine the actual transmitted signal. Then, the in phase and quadrature components of the received communication symbols in the plane of the modulation points are determined. Next, the sum of the in phase components is determined and the sum of the absolute value of the quadrature components is determined. The channel state is then determined from the

ratio of the sum of the in phase components to the sum of the absolute value of the quadrature components. The present invention also contemplates determining the channel state from the phase error of the received signals from the modulation points. The present invention further contemplates determining the channel state from the distance error of received signals from the modulation points.

In accordance with another aspect of the present invention, method and apparatus for erasing communication signals in accordance with the channel state are provided. In accordance with the method, the channel state is determined when the communication signal is received and then signals are erased if the channel state is not better than a predetermined level.

In accordance with a further aspect of the present invention, method and apparatus for selecting one of two communication signals for processing when diversity signals are received. In accordance with the method, a first channel state is determined when the first of two diversity communication signals is received and a second channel state is determined when the second of the two diversity communication signals is received. Then, based on the values of the first and the second channel states, one of the two diversity communication signals is selected for further processing.

The invention will now be described in connection with certain illustrated embodiments; however, it should be clear to those skilled in the art that various modifications, additions and subtractions can be made without departing from the spirit and scope of the claims.

Description Of The Drawings

FIG. 1 illustrates a wireless communication system in which the apparatus and method of the present invention is used;

FIG. 2 shows the steps used to determine channel state by using the in phase and quadrature components of a received communication signal;

FIG. 3 illustrate a modulation plane and the determination of channel state by using the in phase and quadrature components of received signals as in FIG. 1;

FIGS. 4 and 5 illustrate an alternate process of determining channel state by using phase error of received signals;

FIGS. 6 and 7 illustrate a process for determining channel state by using the Euclidean distance error of received signals and the respective modulation points;

FIG. 8 illustrates the processing apparatus in the subscriber units used to determine channel state in accordance with any of the above processes;

FIG. 9 illustrates the process in accordance with another aspect of the present invention wherein communication signals from one of two diversity channels are selected for processing;

FIG. 10 illustrates the process in accordance with one aspect of the present invention wherein communication signals are erased; and

FIG. 11 illustrates a metric decision zone.

Description Of The Preferred Embodiment

FIG. 1 illustrates a wireless communication system 1 in which the apparatus and method of the present invention can be used. A base station 2 establishes communications with and between a plurality of mobile or portable subscriber units 4 and a plurality of dispatch stations 6. The subscriber units 4 have the ability to communicate with each other and with the dispatch station 6. The communication functions provided preferably include telephony, dispatch, one to one communications, data communications and other communication functions. The communication links are provided between the above described components and over the PSTN.

The system of FIG. 1 preferably establishes communications over a plurality of frequency channels and in a plurality of time slots. The communications over the frequency channels are preferably broken into packets which are "hopped" across the frequency channels -- thus, a communication is transmitted over more than one frequency channel in accordance with a predetermined sequence, as described in United States Patent No. 5,408,496, which is hereby incorporated by reference. Such a system is commonly referred to as a frequency hopping system.

The communications can also be "hopped" across the plurality of time slots. In this case, different parts of a communication are transmitted in different time slots, again in accordance with a predetermined sequence. Further, the communication system 1 is shown as a sectorized system having three sectors 8 to 10. The hopping sequences used

in the sectors 8 to 10 are preferably orthogonal, as explained in United States Patent No. 5,408,496. The present invention, however, is not limited to sectorized communication systems or to frequency and/or time hopped communication systems.

When a subscriber unit 4, a dispatch station 6 or a base station 2 receives a signal, it is desirable to determine the state of the communication channel that the signal was received on. In FIG. 2, the preferred steps used to determine channel state, in accordance with a one embodiment of the present invention, are illustrated. In the first step 100, after the received signals are demodulated, communication signals from one of the plurality of time slots in the time slotted communication system of FIG. 1 are detected.

For illustrative purposes only, assume that communication signals received in the time slot consists of thirty-eight QPSK modulated symbols, each symbol falling into one of four quadrants in a modulation plane, the quadrant being specified by two bits. For example, in FIG. 3, a QPSK modulation plane having four modulation points 102 to 105 in quadrants 0 to 3, respectively, is shown. For each received symbol, the two bits in the symbol determine which quadrant the symbol belongs in.

After demodulation, as part of step 100, hard detection -- a well known process -- assigns each symbol to one of the four quadrants. This process simply determines the value of the received symbol and makes the quadrant assignment. Thus, in FIG. 3, symbol S1, whose bits are 00, is assigned to quadrant 0. Symbol S2, whose bits are 01, is assigned to quadrant 2. Symbol S3, whose bits are 11, is assigned to quadrant 3. Symbol S4, whose bits are 10, is assigned to quadrant 1. This process is performed thirty-nine times, one time for each symbol in the time slot.

Next, in step 106, each symbol is rotated to a selected one of the four quadrants, preferably quadrant 0. This process allows uniform and simpler processing of the received communication signals in accordance with the present invention. If quadrant 0 is selected as the quadrant to which all symbols are rotated to, then the symbols are rotated according to the following:

(1) If the symbol is in quadrant 0, the symbol is not rotated;

(2) If the symbol is in quadrant 2, 90° is added to the symbol phase to rotate the symbol to quadrant 0;

(3) If the symbol is in quadrant 3, 180° is added to the symbol phase to rotate the symbol to quadrant 0; and

(4) If the symbol is in quadrant 1, 270° is added to the symbol phase to rotate the symbol to quadrant 0.

Referring to FIG. 3, this process is illustrated with respect to symbols S1 to S4. Since symbol S1 is in quadrant 0, nothing is done and symbol S1 remains in quadrant 0. Since symbol S2 is in quadrant 2, 90° is added to rotate symbol S2 to quadrant 0. Since symbol S3 is in quadrant 3, 180° is added to rotate symbol S3 to quadrant 0. Since symbol S4 is in quadrant 1, 270° is added to rotate symbol S4 to quadrant 0. Again, this process is performed thirty-nine times, one time for each symbol in the time slot.

Once all the symbols from a time slot have been rotated to the same quadrant, in step 108, the in-phase component of each symbol in the x-y plane, which has axes intersecting the modulation points in the modulation plane as shown in FIG. 3, is determined. Since the symbol is a complex number, this is preferably performed by taking the real component of each symbol, Re(Si), where Si are the symbols in a time slot. Then, in step 110, the quadrature component of each symbol in the x-y plane is determined. Again, since the symbols are complex numbers, this is preferably done by taking the imaginary component of each symbol in the time slot: Imag(Si). In FIG. 3, the calculation of the in-phase component, Real(S1), and the quadrature component, Imag(S1), for one symbol, S1, is illustrated. It is understood however that this process is preferably performed on each rotated symbol in a time slot.

In step 112, the channel state of the frequency channel during the time slot that the symbols were received on is determined from the ratio of the sum of the in-phase components to the sum of the absolute value of the quadrature components. Thus, the in-phase component from each symbol in the time slot is summed. Then, the absolute value of the quadrature component from each symbol is summed. Then the channel state is the ratio of the sum of the in-phase components to the sum of the absolute value of the quadrature components. Thus, channel state, CS, is preferably determined as follows:

$$CS = \frac{\sum_{Slot} \mathrm{Real}\,(Si)}{\sum_{Slot} |\mathrm{Imag}(Si)|}$$

where Si are the symbols in the time slot. In the equation above, the absolute value is used to maintain channel state as a positive number. Other mathematical functions can be used to perform the same task.

In the above equation, it is apparent that the higher the value of CS, the higher the quality of the channel state. Conversely, the lower the value of CS, the lower the quality of the channel state.

In accordance with the present invention, two points -- the nominal modulation point and the received signal point -- are compared to determine channel state. In accordance with this embodiment of the present invention, the calculation of the in-phase and quadrature components, therefore, provides a measure of the variance or error between the received symbol and the actual transmitted symbol as determined by hard detection. If the symbols in a time slot show a small deviation, the channel state is "good" since there was not much distortion. If, on the other hand, there is a lot of deviation in the received symbols, the channel state is "poor".

It will be appreciated that while the above describes a preferred embodiment of determining channel state by processing the symbols in a time slot, the invention has broader applications. The above described processing can be performed on a single communication signal to determine the state of the communication channel on which the signal was received, although the averaging of the received symbols yields a better indication of the channel state. Thus, it is apparent that the processing need not be restricted to the symbols in a time slot -- more or less symbols can be used as desired. Also, the use of the previously described processing steps is not limited to frequency hopping and time hopping communication systems -- they may be used on any type of communication system. In addition, if a plurality of symbols are used, they need not be rotated to one quadrant in the modulation plane as described above; instead the processing can be done within the quadrant that the symbol belongs to and the results averaged accordingly. Further, the processing of the present invention can be used with any modulation scheme.

FIGS. 4 and 5 illustrate the determination of the channel state via an alternate embodiment. Referring to FIG. 4, the first two steps 120 and 122 are the same as steps 100 and 106 previously described with respect to FIG. 2. Thus, in step 120, hard

detection of the demodulated received symbols is performed to determine the modulation point of the demodulated received signal and, in step 122, all of the received signals from a time slot are rotated to one quadrant in the modulation plane. The rotation of four symbols S1 to S4 are illustrated in FIG. 5.

In step 124, the phase error of each rotated symbol is determined. Referring to FIG. 5, it is seen that the phase error, θ(1err), for one demodulated received symbol, S1, is the phase between modulation point 126, θ(mod), and the symbol S1, θ(S1):

$$\theta(1err) = \theta(S1) - \theta(mod)$$

After the phase error for each demodulated received symbol is determined, in step 128, the average phase error of the symbols within a slot is determined using the absolute value of the phase error:

$$\theta\ (\mathrm{avg}) = \sum_{Slot} |\theta(ierr)| = \sum_{Slot} |\theta(Si) - \theta(\mathrm{mod})|$$

where i is the symbol number in a time slot and θ (Si) is the phase of each rotated symbol Si within the time slot.

Alternatively, the average phase error of the symbols within a slot can be determined using the square of the phase error from each symbol:

$$\theta\ (\mathrm{avg}) = \sum_{Slot} (\theta(ierr))^2 = \sum_{Slot} (\theta(Si) - \theta(\mathrm{mod}))^2$$

where i is the symbol number in a time slot and θ (Si) is the phase of each rotated symbol Si within the time slot.

Next, in step 130, the channel state, CS, is determined in accordance with θ(avg). The exact relationship between the channel state and the average phase error (i.e. what is "good" and what is "poor") is preferably determined empirically for each communication system, but in general, the greater the average phase error, the worse the channel state and the lower the average phase error, the better the channel state.

FIGS. 6 and 7 illustrate the determination of the channel state via another alternate embodiment. Referring to FIG. 6, once again, the first two steps 140 and 142 are the same as steps 100 and 106 previously described with respect to FIG. 2. Thus, in step

140, hard detection of the received symbols is performed to determine the modulation point of the received signal and, in step 142, all of the received symbols from a time slot are rotated to one quadrant in the modulation plane. The rotations of four symbols S1 to S4 are illustrated in FIG. 7.

In step 144, the Euclidean distance error of each rotated signal is determined. Referring to FIG. 7, it is seen that the Euclidean distance error, E1, for one received signal, S1, is the distance between the modulation point of the quadrant that the received signal is in -- in this case modulation point 146 -- and the signal S1. Then, in step 148, the absolute value of the Euclidean distance error for each received signal is determined. In step 150, the channel state, CS, is determined from the average distance error Ei of symbols within a time slot:

$$CS = \sum_{Slot} |Ei|$$

In step 152, it is further preferred to normalize CS to the average absolute value of the symbols in a time slot:

$$CS = \frac{\sum_{Slot} |Ei|}{\sum_{Slot} |Si|}$$

As before, the exact relationship between the channel state and the average Euclidean distance error is preferably determined empirically for each communication system, but in general, the greater the average distance error, the worse the channel state and the lower the average distance error, the better the channel state.

Referring to FIG. 8, the receiving, processing and display equipment of the subscriber unit 4 is illustrated. The receive equipment of the base station 2 and the dispatch station 6 is substantially similar. The transmit circuitry, which is not important to the present invention, includes a transmitter 200 and a gain control circuit 202 which are controlled, in part, by a frequency synthesizer 204. Signals are transmitted through a duplexer 206 and an antenna 208.

On the receive side, communication signals are received on the antenna 208 and on a second antenna 210. Two receivers 212 and 214 receive the signals from the antennas

208 and 210, respectively. The frequency channel of reception is programmed into the receivers 212 and 214 by the synthesizer 204. The receivers 212 and 214 are gain and frequency controlled by a circuit 216.

The received signals from both antennas 208 and 210 are preferably sent to the modem 218. The modem 218 converts the received signals to digital signals. The modem 218 preferably includes a digital signal processor (DSP), preferably Analog Devices 2111, 2171 or 2181, and a ASIC device 230. These devices process the signals received from both receivers 212 and 214 in accordance with the previously described steps.

The processing is controlled by a controller 220. The processed signals are further processed to extract voice and other information by a voice processing package (VPP) 222 and the processed communication signals are provided to a user interface 224 through the interface 226. The user interface 224 includes the usual devices found in subscriber units, including a display, speakers and microphones.

The circuitry of FIG. 8, can be used to calculate the variation or error associated with received communication signals in accordance with any of the previously described processes. Thus, the circuitry of FIG. 8 can calculate in-phase and quadrature components, phase error and/or distance errors associated with the received signals.

The channel state CS that is computed from received signals by the processing circuitry of FIG. 8 can be utilized to select between the two signals simultaneously received on the antennas 208 and 210 and by the receivers 212 and 214, respectively. This reception of dual signals is commonly referred to as "diversity" reception.

Referring to FIG. 9, the steps for making the selection between the two diversity signals, which are received at the same time, are illustrated. In step 300, the channel state for the first receive channel, CS1, which is generated by any of the previously described processes or by any other process, from the signals (or signal) received on antenna 208, is determined. In step 302, the channel state for the second receive channel, CS2, which is generated as previously described or by any other process, from the signals (or signal) received on antenna 210, is determined. Then in step 304, the channel states from each receive channel are compared. If we assume that the process of

FIGS. 2 and 3 are used to calculate the channel state for each receive channel, then the following comparison is made:

$$CS1 > CS2?$$

If CS1 is greater than CS2, then in step 306, channel 1 is selected. Thus, the signals from antenna 208 are selected for processing. On the other hand, if CS1 is not greater than CS2, channel 2 is selected so that the signals from the antenna 210 are selected for processing (step 308). As before, the processing is performed by the circuitry of FIG. 8, in particular, in the digital signal processor in the modem 218.

The selection of signals from one of two channels for processing is preferably done every time channel states are recalculated. Thus, where the channel states for the diversity channels are calculated for each time slot, it is the signals from the time slot of one of the channels that are selected for processing. A new selection is then made for every time slot. If channel state is determined from another period of signals, by way of example only, from a single signal, then the signals from the period that is used to calculate channel state are the ones selected for processing.

The channel state CS that is computed from received signals by the processing circuitry of FIG. 8 can also be utilized to erase signals which are not received with some minimum confidence level. The confidence level is preferably determined in accordance with the channel state.

Referring to FIG. 10, the preferred steps for performing erasures of signals that are not received with some minimum confidence level are shown. In step 350, the channel state of a receive signal or of a group of receive signals -- for example, the signals in a selected time slot -- is determined. This can either be the channel state of the selected one of the two receive channels or it can be the channel state of a single receive channel. Then, in step 352, the channel state is compared to a threshold, th. If the comparison fails, that is, if the channel state is not better than some value represented by the threshold, it is preferred to erase the signal in step 354. If the comparison passes, that is if the channel state is better than some value represented by the threshold, in step 356,

the signal is passed on for further processing. Whether "better" means greater or less than the threshold depends on the process used to determine channel state.

The number of signals erased preferably coincides with the number of signals used to calculate the channel state. Thus, where the channel state is calculated from signals in a time slot, it is the signals from the time slot of one of the channels that are erased in step 354. If channel state is determined from another period of signals, then the signals from the period that is used to calculate channel state are the signals that are erased in step 354. So for example only, if channel state were calculate based on a single received signal, then it is preferred to erase only the single signal in step 354.

The preferred value of the threshold, th, depends on the method of calculating channel state. If channel state is calculated via the in-phase and quadrature components of the received signals in a time slot, then the threshold is preferably 3.5 and the erasure is made in step 354 if the channel state of received signals in a time slot falls below that number. If the channel state is calculated via the phase error of the received signals in a time slot, then the threshold th is preferably 0.085 and the erasure is made in step 354 if the channel state of the received signals in the time slot exceeds that number.

In step 354, the erasure is preferably made by setting a metric, which is a number associated with each received signal that represents the confidence level that the received signal was properly received, to a predetermined value, typically the lowest value. When the circuitry of FIG. 8 processes the received signals, it preferably erases the signals with the lowest metric by setting those signals to zero.

In accordance with another embodiment of the present invention, a communication device receiving a communication signal performs two measures of channel state and uses one of the channel states to perform diversity selection and the other channel state to perform erasures. In a preferred embodiment, the channel state determined by phase error measurements (FIGS. 4 and 5) is used to perform erasures of poorly received signals while the channel state determined by distance error measurements (FIGS. 6 and 7) is used to select one of the two diversity channels.

Pseudocode

The previously described steps of determining channel state from the in-phase and quadrature components of received signals from two channels, the steps of selecting between diversity signals and the steps of erasing signals which are not received with some minimum confidence level, are further described by the following pseudocode:

Calculate Channel State

CS_X = 0.0	Initialize channel state variables
CS_Y = 0.0	
for I: = 1 to 38 do	For each symbol in a time slot
Begin	
U:=R(I)R*(I-1)	Perform for differential detection (different detection equations are used for different detection schemes)
MSD, MHD:=according to routine	Generate metrics, MSD and MHD, for soft and hard decisions, respectively; see the metrics generation routine
MET0[i] = TABLE1(MSD);	Apply MSD to Table 1 (see below) which is an example of the metrics preferred for a specific communication system. The table generates a 3 bit metric, MET0[i], where i is the symbol number within the time slot being processed. One bit of the metric MET0[i] is I and two bits are the confidence level.
MET1[i] = TABLE2(MSD);	Apply MSD to Table 2 (see below). The table generates a 3 bit metric, MET1[i], where i is the symbol number within the

	time slot being processed. One bit of the metric MET1[i] is Q and two bits are the confidence level.
If MHD = 0, then W:=U • (1-j);	Rotate to quadrant 0 based on hard decision
If MHD = 1, then W:=U • (-1-j);	
If MHD = 3, then W:=U • (-1+j);	
If MHD = 2, then W:=U • (1+j);	
CS_X:=CS_X +Re(W)	Sum in-phase components of rotated signal
CS_Y:=CS_Y + |Imag(W)|	Sum absolute value of quadrature components of rotated signal
end;	

<u>Perform Erasure</u>

If CS_X < CS_Y • CSmin, then	CSmin is the threshold to which CS_X/CS_Y is compared to
Begin	
For I:=1 to 38 do	For each symbol in a time slot, erase by setting confidence level bits to 00
Begin	
if MET0[i] < 4 then MET0[i]:=0	For I = 0 (represented by 0XX, i.e. < 4, where 0 is the bit and XX is the confidence level associated with the bit) erase by setting confidence level to the minimum value, 00, which causes the digital signal processor to erase the bit. The result is MET 0[i] = 0.
if MET0[i] > 3 then MET0[i]:=4	For I = 1 (represented by 1XX, i.e. > 3,

where 1 is the bit and XX is the confidence level associated with the bit) erase by setting confidence level to the minimum value, 00, which causes the digital signal processor to erase the bit. The result is MET0[i] = 4.

if MET1[i] < 4 then MET1[i]:=0

For Q = 0 (represented by 0XX, i.e. < 4, where 0 is the bit and XX is the confidence level associated with the bit) erase by setting confidence level to the minimum value, 00, which causes the digital signal processor to erase the bit. The result is MET 1[i] = 0.

if MET1[i] > 3 then MET1[i]:=4

For I = 1 (represented by 1XX, i.e. > 3, where 1 is the bit and XX is the confidence level associated with the bit) erase by setting confidence level to the minimum value, 00, which causes the digital signal processor to erase the bit. The result is MET0[i] = 4.

end;

end;

Perform diversity selection

A0 := CS_X0 • CS_Y1

0 and 1 indicate the diversity channels

A1 := CS_X1 • CS_Y0

For i=1 to 38

Set M[i] = MET1[i]:MET0[i]

M[i] becomes a six bit metric representing I and Q and the confidence levels. For each i, select the values from

channel 0 if A0 > A1 and select the values from channel 1 if A1 $\geq$ A0.

Metrics Generation Routine

Can be calculated via table but the following generator saves DSP memory

Calculate $|I| = |Re(U)|$

Calculate $|Q| = |Im(U)|$

Determine a section S in the first quadrant

Referring to FIG. 11, there are 3 sectors in each quadrant. The sector that a symbol falls in is determined here. The 3 sectors are identified by S=0, 4, and 44.

If $|Q| \leq |I| \tan 30°$, then S=44

If $|I| \bullet \tan 30° < |Q| \leq |I| \bullet \tan 60°$ then S=0

If $|I| \bullet \tan 60° < |Q|$, then S=4

Calculate $\gamma = (Q^2 + I^2)^{1/2}$

Calculate rings:

R=3 $0 \leq \gamma \leq 1.225.10^{-3}$

The boundaries should be less than 1; see FIG. 11 for the generated metric decision zones, including the five possible rings.

R=2 $1.225.10^{-3} < \gamma \leq 4.9.10^{-3}$

R=1 $4.9.10^{-3} < \gamma \leq 0.0196$

R=0 $0.0196 < \gamma \leq 0.49$

$R=3 \qquad \gamma > 0.49$

Calculate metrics:

$MSD = S+R$ and $MHD = 0$: $Q \geq 0$, $I \geq 0$	The metrics (MHD for hard detection and MSD for soft detection) are determined here based on the values of S and R. MHD places the signal on one of four quadrants. MSD places the signal on the metric decision zone in FIG. 1. For example, if MHD =1 (i.e. quadrant 1) and S = 44 and R =1, then MSD =17. See zone 17 in quadrant 1 of FIG. 11.
$MSD = [(12-S) \bmod 48] + R$ and $MHD = 1$, for $Q \geq 0$, $I<0$	mod indicates modular arithmetic
$MSD = [(24+S) \bmod 48] + R$ and $MHD = 3$, for $Q<0$, $I<0$	
$MSD = [(36-S) \bmod 48] + R$ and $MHD = 2$, for $Q<0$, $I \geq 0$	

TABLE1-LSB Metrics

IN	OUT	IN	OUT
0	3	24	7
1	2	25	6
2	1	26	5
3	0	27	4
4	2	28	6
5	1	29	5
6	0	30	4
7	0	31	4
8	6	32	2
9	5	33	1
10	4	34	0
11	4	35	0
12	7	36	3
13	6	37	2
14	5	38	1
15	4	39	0
16	7	40	3
17	6	41	2
18	5	42	1
19	4	43	0
20	7	44	3

21	6	45	2
22	5	46	1
23	4	47	0

TABLE 2 - MSB Metrics

IN	OUT	IN	OUT
0	3	24	7
1	2	25	6
2	1	26	5
3	0	27	4
4	3	28	7
5	2	29	6
6	1	30	5
7	0	31	4
8	3	32	7
9	2	33	6
10	1	34	5
11	0	35	4
12	3	36	7
13	2	37	6
14	1	38	5
15	0	39	4
16	2	40	6

17	1	41	5
18	0	42	4
19	0	43	4
20	6	44	2
21	5	45	1
22	4	46	0
23	4	47	0

An example will now be given that illustrates the processing of one symbol and the effect of an erasure on that symbol. Suppose that the first symbol in a time slot, S1, is received and that, when applied to the metric generation routine, yields S = 44, R = 1 and MHD = 1. Applying these facts to the MSD equation:

$$MSD = [(12 - S) \bmod 48] + R = [(12 - 44) \bmod 48] + 1 = 17$$

Thus, the symbol S1 falls in zone 17 in quadrant 1 in FIG. 11.

Next MET0[1] and MET1[1] are generated by applying MSD to TABLE 1 and TABLE 2, respectively:

MET0[1] = 6 = 110

MET1[1] = 1 = 001

The first bit of MET0[1] specifies I = 1 and the next two bits, 10, specify a confidence level (00 is the lowest level, 11 is the highest). The first bit of MET1[1] specifies Q = 0 and the next two bits specify a confidence level.

Erasures are made, if at all, once all of the symbols in the time slot have been processed. If the channel state falls below a threshold, CS min, then the confidence bits for all symbols in a time slot, Si, are set to "null values", which are of low level of confidence, like 00. The processing then changes the values of the I and the Q bits to null metrics which do not contribute to an erroneous decision at the error correcting

process. Essentially, the erasure means that the I and Q information content from the time slot is not used. Thus, if an erasure needs to be made, the following occurs:

$$MET0[1] = 4 = 100$$

$$MET1[1] = 0 = 000$$

This is repeated for all symbols in the time slot.

It is understood that changes may be made in the above description without departing from the scope of the invention. It is accordingly intended that all matter contained in the above description and in the drawings be interpreted as illustrative rather than limiting.

We claim:

1. A method of deriving the state of a channel on which communication signals are transmitted and received, comprising the steps of:

determining the modulation point of the signal as transmitted;

determining the variance between the signal as received and the modulation point; and

determining the state of the channel in accordance with the variance.

2. The method of claim 1, wherein the phase variance between the signal as received and the modulation point is determined.

3. The method of claim 1, wherein the distance between the signal as received and the modulation point is determined.

4. Apparatus for deriving the state of a channel on which communication signals are transmitted and received, comprising:

means for determining the modulation point of the signal as transmitted;

means for determining the variance between the signal as received and the modulation point; and

means for determining the state of the channel in accordance with the variance.

5. The apparatus of claim 4, wherein the phase variance between the signal as received and the modulation point is determined.

6. The apparatus of claim 4, wherein the distance between the signal as received and the modulation point is determined.

7. A method of deriving the state of a channel on which communication signals are transmitted and received, comprising the steps of:

for a plurality of signals, determining the modulation point of the signals as transmitted;

for each of the plurality of signals, determining the variance between the signal as received and the modulation point; and

determining the state of the channel in accordance with the average variance of each of the plurality of signals.

8. The method of claim 7, wherein the signals from a time slot are used.

9. The method of claim 7, wherein the determined variance is the phase difference between the signal as received and the modulation point.

10. The method of claim 9, wherein the signals from a time slot are used.

11. The method of claim 10, wherein the state of the channel is determined in accordance with the following equation:

$$CS = \sum_{Slot} |\theta(Si) - \theta(\text{mod})|$$

where θ(Si) is the phase of a received signal and θ(mod) is the phase of the modulation point of the transmitted signal.

12. The method of claim 7, wherein the determined variance is the distance between the signal as received and the modulation point.

13. The method of claim 12, wherein the signals from a time slot are used.

14. The method of claim 13, wherein the state of the channel is determined in accordance with the following equation:

$$CS = \sum_{Slot} |Ei|$$

wherein Ei is the distance between a received signal and the modulation point of the transmitted signal.

15. Apparatus for deriving the state of a channel on which communication signals are transmitted and received, comprising:

means for determining the modulation point of the signals as transmitted for a plurality of signals;

means for determining the variance between the signal as received and the modulation point for each of the plurality of signals; and

means for determining the state of the channel in accordance with the average variance of each of the plurality of signals.

16. The apparatus of claim 15, wherein the signals from a time slot are used.

17. The apparatus of claim 16, wherein the determined variance is the phase difference between the signal as received and the modulation point.

18. The apparatus of claim 17, wherein the signals from a time slot are used.

19. The apparatus of claim 18, wherein the state of the channel is determined in accordance with the following equation:

$$CS = \sum_{Slot} |\theta(Si) - \theta(\text{mod})|$$

where θ(Si) is the phase of a received signal and θ(mod) is the phase of the modulation point of the transmitted signal.

20. The apparatus of claim 15, wherein the determined variance is the distance between the signal as received and the modulation point.

21. The apparatus of claim 20, wherein the signals from a time slot are used.

22. The apparatus of claim 21, wherein the state of the channel is determined in accordance with the following equation:

$$CS = \sum_{Slot} |Ei|$$

wherein Ei is the distance between a received signal and the modulation point of the transmitted signal.

23. A method for processing a first communication signal and a second communication signal received by a communication device at approximately the same time on a first and second communication channel, respectively, comprising the steps of:

determining the state of the first communication channel;

determining the state of the second communication channel; and

selecting between the first communication signal and the second communication signal based on the state of the first communication channel and on the state of the second communication channel.

24. The method of claim 23, wherein the first communication signal is selected for further processing when the state of the first communication channel is better than the state of the second communication channel and wherein the second communication signal is selected for further processing when the state of the second communication channel is better than the state of the first communication channel.

25. The method of claim 24, wherein the channel state is determined by determining the modulation point of a signal as transmitted on a communication channel, by determining the variance between the signal as received and the modulation point and then determining the channel state in accordance with the variance.

26. The method of claim 24, wherein the channel state is determined by determining the modulation point of each of a plurality of signals as transmitted on a communication channel, by determining the variance between each of the plurality of signals as received

and the modulation points and then determining the channel state in accordance with the average variance.

27. The method of claim 26, wherein the selection of signals from the first or second communication channel is made based on the number of signals used to determine channel state.

28. The method of claim 26, wherein the plurality of signals used to determine channel state come from a time slot.

29. The method of claim 28, wherein the selection of signals for further processing is made every time slot.

30. The method of claim 24, wherein the channel state is determined by comparing the phase of a signal as received to the phase of the modulation point of the signal as transmitted.

31. The method of claim 30, wherein the channel state is determined by comparing the phase of a signal as received to the phase of the modulation point of the signal as transmitted for a plurality of signals and then using the average variation.

32. The method of claim 31, wherein the selection is made every time a new plurality of signals is used to determine channel state.

33. The method of claim 31, wherein the signals within a time slot are used to determine channel state and wherein the selection is made for every time slot.

34. The method of claim 24, wherein the channel state is determined by comparing the distance between a signal as received and the modulation point of the signal as transmitted.

35. The method of claim 34, wherein the channel state is determined by comparing the distance between a signal as received and the modulation point of the signal as transmitted for a plurality of signals and then using the average distance.

36. The method of claim 35, wherein the selection is made everytime a new plurality of signals is used to determine channel state.

37. The method of claim 35, wherein the signals within a time slot are used to determine channel state and wherein the selection is made for every time slot.

38. Apparatus for processing a first communication signal and a second communication signal received by a communication device at approximately the same time on a first and second communication channel, respectively, comprising:

means for determining the state of the first communication channel;

means for determining the state of the second communication channel; and

means for selecting between the first communication signal and the second communication signal based on the state of the first communication channel and on the state of the second communication channel.

39. The apparatus of claim 38, wherein the first communication signal is selected for further processing when the state of the first communication channel is better than the state of the second communication channel and wherein the second communication signal is selected for further processing when the state of the second communication channel is better than the state of the first communication channel.

40. The method of claim 38, wherein the channel state is determined by determining the modulation point of a signal as transmitted on a communication channel, by determining the variance between the signal as received and the modulation point and then determining the channel state in accordance with the variance.

41. The apparatus of claim 38, wherein the channel state is determined by determining the modulation point of each of a plurality of signals as transmitted on a communication channel, by determining the variance between each of the plurality of signals as received and the modulation points and then determining the channel state in accordance with the average variance.

42. The method of claim 41, wherein the selection of signals from the first or second communication channel is made based on the number of signals used to determine channel state.

43. The apparatus of claim 41, wherein the plurality of signals used to determine channel state come from a time slot.

44. The apparatus of claim 43, wherein the selection of signals for further processing is made every time slot.

45. The apparatus of claim 38, wherein the channel state is determined by comparing the phase of a signal as received to the phase of the modulation point of the signal as transmitted.

46. The apparatus of claim 45, wherein the channel state is determined by comparing the phase of a signal as received to the phase of the modulation point of the signal as transmitted for a plurality of signals and then using the average variation.

47. The apparatus of claim 46, wherein the selection is made every time a new plurality of signals is used to determine channel state.

48. The apparatus of claim 46, wherein the signals within a time slot are used to determine channel state and wherein the selection is made for every time slot.

49. The apparatus of claim 38, wherein the channel state is determined by comparing the distance between a signal as received and the modulation point of the signal as transmitted.

50. The apparatus of claim 49, wherein the channel state is determined by comparing the distance between a signal as received and the modulation point of the signal as transmitted for a plurality of signals and then using the average distance.

51. The apparatus of claim 50, wherein the selection is made everytime a new plurality of signals is used to determine channel state.

52. The apparatus of claim 50, wherein the signals within a time slot are used to determine channel state and wherein the selection is made for every time slot.

53. A method of processing communication signals, comprising the steps of:

determining the state of a communication channel on which a communication signal is received;

comparing the state of the communication channel to a threshold; and

erasing the communication signal if the state of the communication channel does not exceed a threshold.

54. The method of claim 53, wherein the erasure is performed by setting the received communication signal to a null value.

55. The method of claim 53, wherein the channel state is determined by determining the modulation point of a signal as transmitted on a communication channel, by determining the variance between the signal as received and the modulation point and then determining the channel state in accordance with the variance.

56. The method of claim 53, wherein the channel state is determined by determining the modulation point of each of a plurality of signals as transmitted on a communication channel, by determining the variance between each of the plurality of signals as received and the modulation points and then determining the channel state in accordance with the average variance.

57. The method of claim 56, wherein the number of signals erased corresponds to the number of signals used to determine channel state.

58. The method of claim 56, wherein the plurality of signals used to determine channel state come from a time slot.

59. The method of claim 58, wherein the decision to erase signals is made every time slot.

60. The method of claim 53, wherein the channel state is determined by comparing the phase of a signal as received to the phase of the modulation point of the signal as transmitted.

61. The method of claim 60, wherein the channel state is determined by comparing the phase of a signal as received to the phase of the modulation point of the signal as transmitted for a plurality of signals and then using the average variation.

62. The method of claim 61, wherein the decision to erase is made every time a new plurality of signals is used to determine channel state.

63. The method of claim 61, wherein the signals within a time slot are used to determine channel state and wherein the decision to erase is made every time slot.

64. The method of claim 53, wherein the channel state is determined by comparing the distance between a signal as received and the modulation point of the signal as transmitted.

65. The method of claim 64, wherein the channel state is determined by comparing the distance between a signal as received and the modulation point of the signal as transmitted for a plurality of signals and then using the average distance.

66. The method of claim 65, wherein the decision to erase is made everytime a new plurality of signals is used to determine channel state.

67. The method of claim 65, wherein the signals within a time slot are used to determine channel state and wherein the decision to erase is made every time slot.

68. Apparatus for processing communication signals, comprising:

means for determining the state of a communication channel on which a communication signal is received;

means for comparing the state of the communication channel to a threshold; and

means for erasing the communication signal if the state of the communication channel does not exceed a threshold.

69. The apparatus of claim 68, wherein the erasure is performed by setting the received communication signal to a null value.

70. The apparatus of claim 68, wherein the channel state is determined by determining the modulation point of a signal as transmitted on a communication channel, by determining the variance between the signal as received and the modulation point and then determining the channel state in accordance with the variance.

71. The apparatus of claim 68, wherein the channel state is determined by determining the modulation point of each of a plurality of signals as transmitted on a communication channel, by determining the variance between each of the plurality of signals as received and the modulation points and then determining the channel state in accordance with the average variance.

72. The apparatus of claim 68, wherein the number of signals erased corresponds to the number of signals used to determine channel state.

73. The apparatus of claim 68, wherein the plurality of signals used to determine channel state come from a time slot.

74. The apparatus of claim 73, wherein the decision to erase signals is made every time slot.

75. The apparatus of claim 68, wherein the channel state is determined by comparing the phase of a signal as received to the phase of the modulation point of the signal as transmitted.

76. The apparatus of claim 75, wherein the channel state is determined by comparing the phase of a signal as received to the phase of the modulation point of the signal as transmitted for a plurality of signals and then using the average variation.

77. The apparatus of claim 76, wherein the decision to erase is made every time a new plurality of signals is used to determine channel state.

78. The apparatus of claim 76, wherein the signals within a time slot are used to determine channel state and wherein the decision to erase is made every time slot.

79. The apparatus of claim 68, wherein the channel state is determined by comparing the distance between a signal as received and the modulation point of the signal as transmitted.

80. The apparatus of claim 79, wherein the channel state is determined by comparing the distance between a signal as received and the modulation point of the signal as transmitted for a plurality of signals and then using the average distance.

81. The method of claim 80, wherein the decision to erase is made everytime a new plurality of signals is used to determine channel state.

82. The apparatus of claim 80, wherein the signals within a time slot are used to determine channel state and wherein the decision to erase is made every time slot.

83. A method of processing a first communication signal and a second communication signal received by a communication device at approximately the same time on a first and a second communication channel, respectively, comprising the steps of:

determining the state of the first communication channel in accordance with a first process;

determining the state of the second communication channel in accordance with the first process;

selecting between the first communication signal and the second communication signal based on the state of the first communication channel and on the state of the second communication channel as determined by the first process;

determining the state of the selected communication channel in accordance with a second process;

comparing the state of the selected communication channel to a threshold; and

erasing the signals of the selected communication channel if the state of the communication channel does not exceed the threshold.

84. Apparatus for processing a first communication signal and a second communication signal received by a communication device at approximately the same time on a first and a second communication channel, respectively, comprising:

means for determining the state of the first communication channel in accordance with a first process;

means for determining the state of the second communication channel in accordance with the first process;

means for selecting between the first communication signal and the second communication signal based on the state of the first communication channel and on the state of the second communication channel as determined by the first process;

means for determining the state of the selected communication channel in accordance with a second process;

means for comparing the state of the selected communication channel to a threshold; and

means for erasing the signals of the selected communication channel if the state of the communication channel does not exceed the threshold.

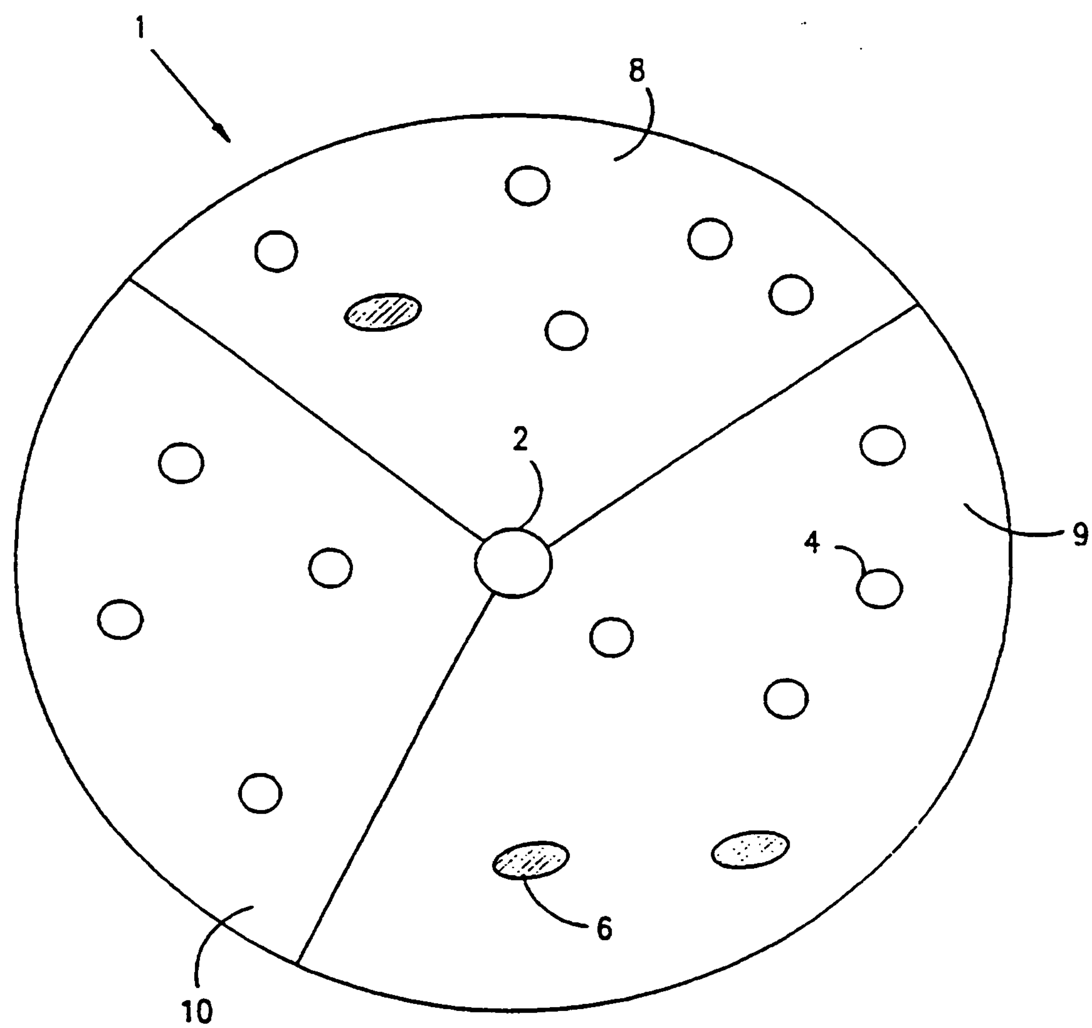
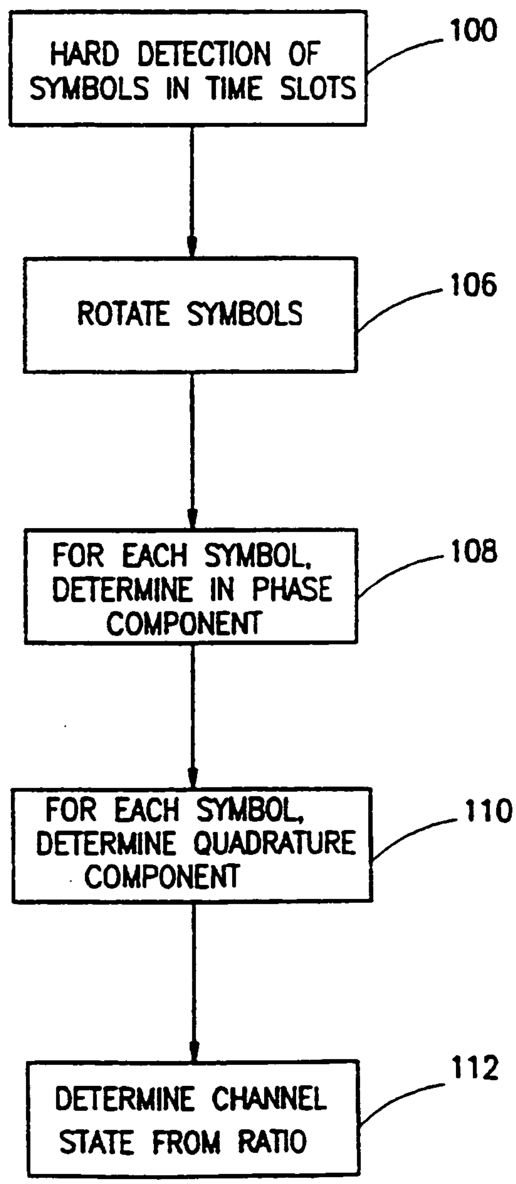


FIG. 1

FIG. 2


HARD DETECTION OF SYMBOLS IN TIME SLOTS
100
ROTATE SYMBOLS
106
FOR EACH SYMBOL, DETERMINE IN PHASE COMPONENT
108
FOR EACH SYMBOL, DETERMINE QUADRATURE COMPONENT
110
DETERMINE CHANNEL STATE FROM RATIO
112

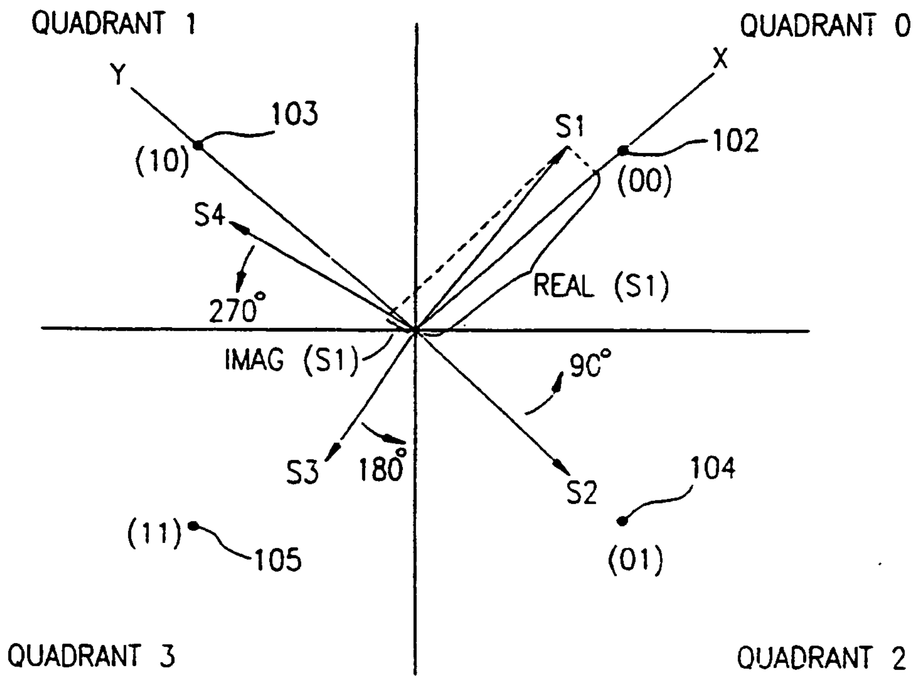
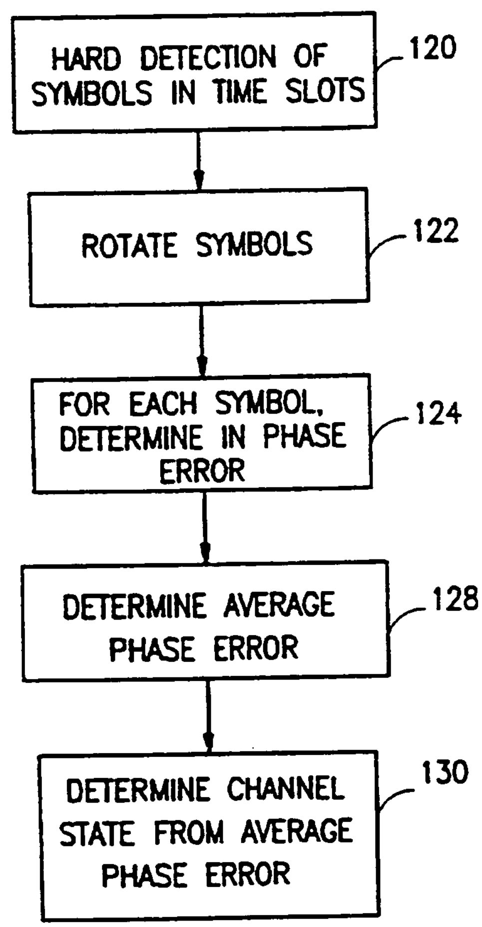

QUADRANT 1
QUADRANT 0
Y
X
103
(10)
S1
102
(00)
S4
REAL (S1)
270°
IMAG (S1)
90°
S3
180°
S2
104
(11)
105
(01)
QUADRANT 3
QUADRANT 2

FIG. 3

FIG. 4


HARD DETECTION OF SYMBOLS IN TIME SLOTS
120
ROTATE SYMBOLS
122
FOR EACH SYMBOL, DETERMINE IN PHASE ERROR
124
DETERMINE AVERAGE PHASE ERROR
128
DETERMINE CHANNEL STATE FROM AVERAGE PHASE ERROR
130

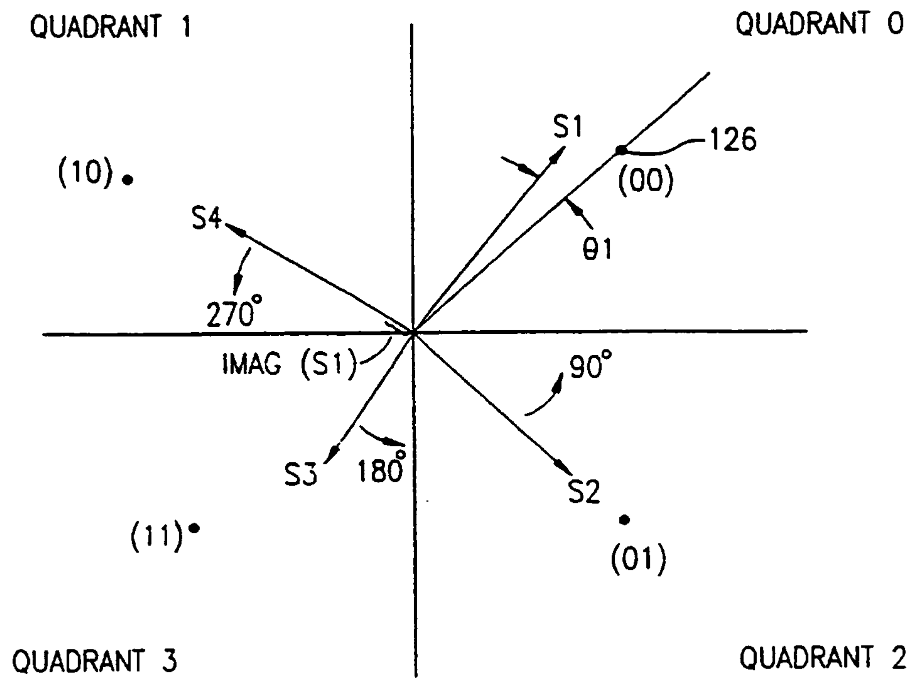
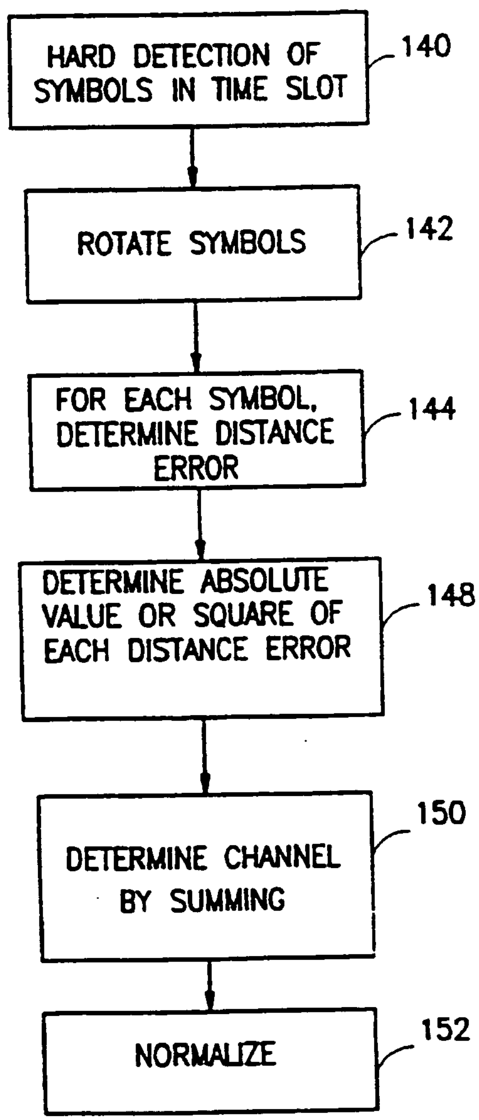

QUADRANT 1
QUADRANT 0
S1
126
(10)
(00)
S4
θ1
270°
IMAG (S1)
90°
S3
180°
S2
(11)
(01)
QUADRANT 3
QUADRANT 2

FIG. 5

FIG. 6


HARD DETECTION OF SYMBOLS IN TIME SLOT
140
ROTATE SYMBOLS
142
FOR EACH SYMBOL, DETERMINE DISTANCE ERROR
144
DETERMINE ABSOLUTE VALUE OR SQUARE OF EACH DISTANCE ERROR
148
DETERMINE CHANNEL BY SUMMING
150
NORMALIZE
152

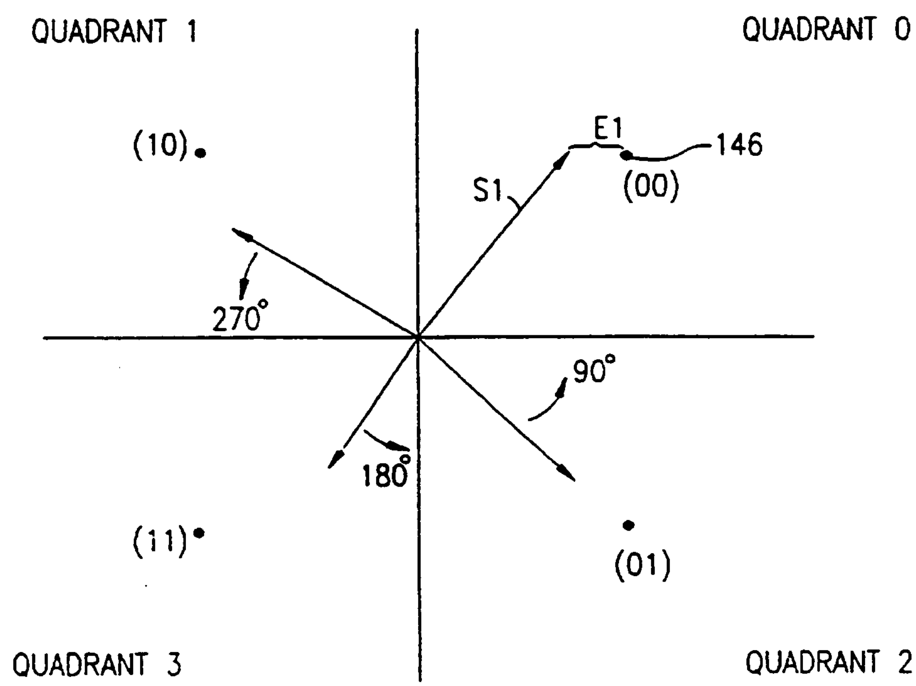

QUADRANT 1
QUADRANT 0
(10)
E1
146
S1
(00)
270°
90°
180°
(11)
(01)
QUADRANT 3
QUADRANT 2

FIG. 7

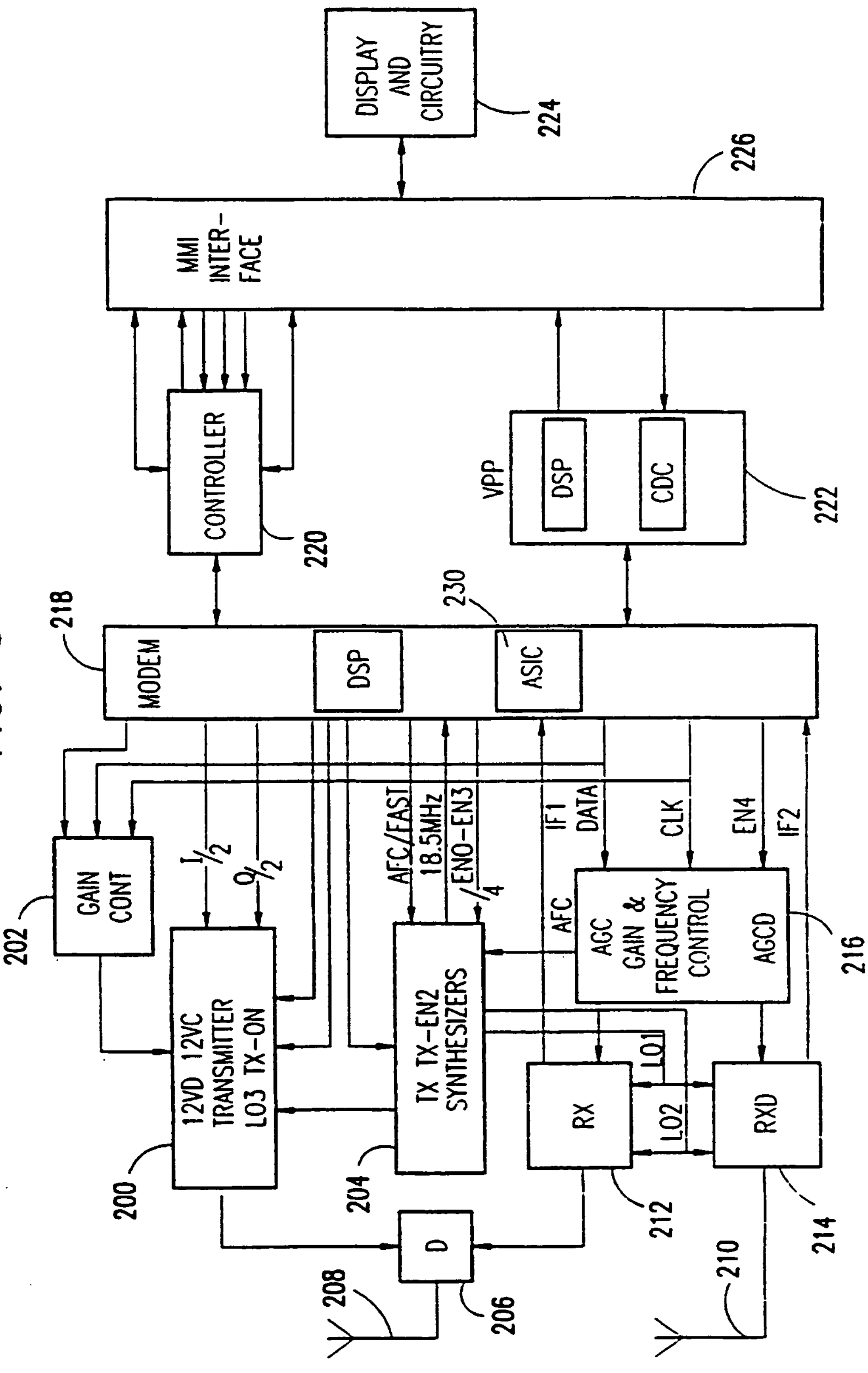

DISPLAY AND CIRCUITRY
224
226
MMI INTER-FACE
CONTROLLER
220
VPP
DSP
CDC
222
218
MODEM
DSP
230
ASIC
GAIN CONT
202
I/2
Q/2
AFC/FAST
18.5MHz
/ENO-EN3
/4
IF1
DATA
CLK
EN4
IF2
AFC
AGC GAIN & FREQUENCY CONTROL AGCD
216
12VD 12VC TRANSMITTER LO3 TX-ON
200
TX TX-EN2 SYNTHESIZERS
204
RX
212
LO1
LO2
RXD
214
D
206
208
210

FIG. 8

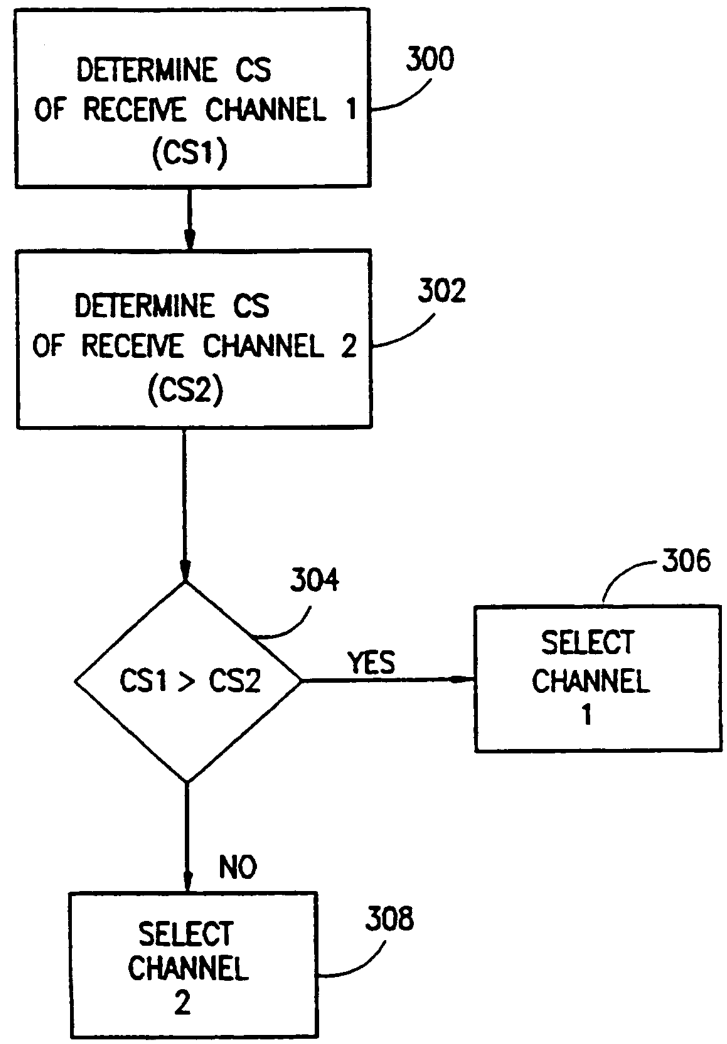

DETERMINE CS
OF RECEIVE CHANNEL 1
(CS1)
300
DETERMINE CS
OF RECEIVE CHANNEL 2
(CS2)
302
304
CS1 > CS2
YES
306
SELECT
CHANNEL
1
NO
SELECT
CHANNEL
2
308

FIG. 9

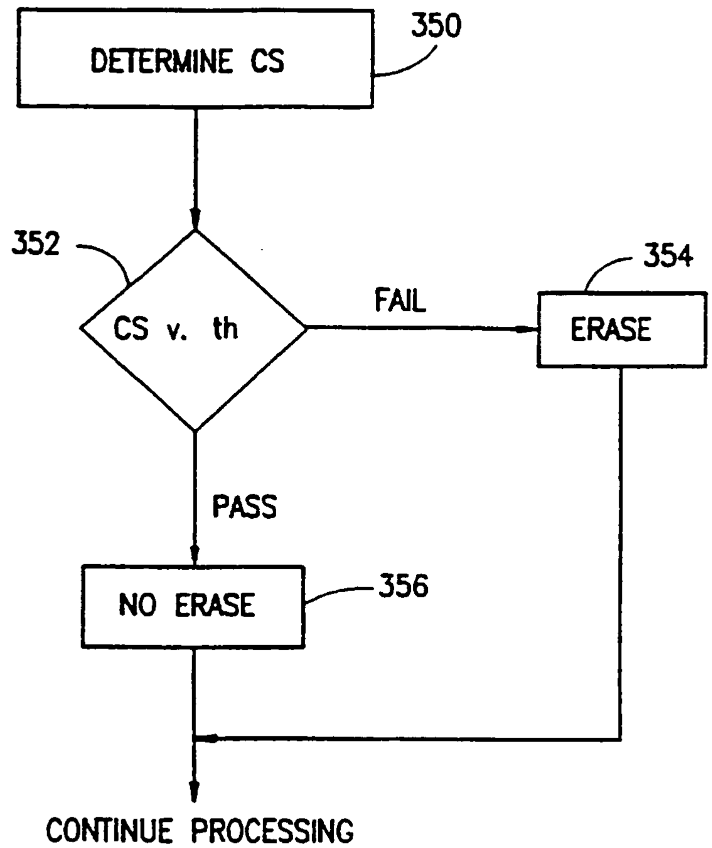

DETERMINE CS
350
352
CS v. th
FAIL
354
ERASE
PASS
NO ERASE
356
CONTINUE PROCESSING

FIG. 10

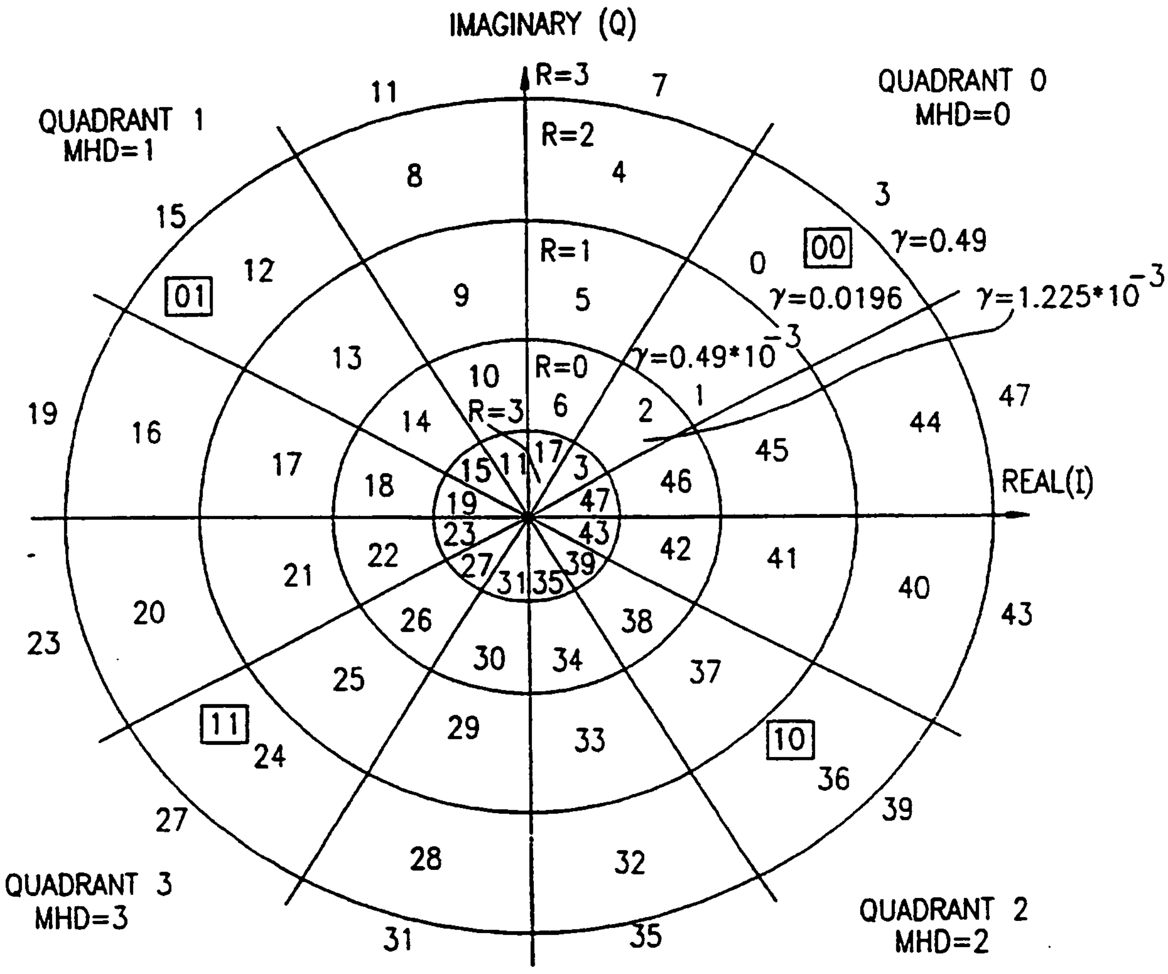

IMAGINARY (Q)
QUADRANT 0
MHD=0
QUADRANT 1
MHD=1
QUADRANT 2
MHD=2
QUADRANT 3
MHD=3
REAL(I)
R=3
R=2
R=1
R=0
00
01
10
11
γ=0.49
γ=0.0196
γ=0.49*10^-3
γ=1.225*10^-3

FIG. 11